



SNOW MELT DRIVEN FLOW INCREASE DEFINITION DRAFT TECHNICAL MEMORANDUM

TO: Nikia Green, Daryl Reed
FROM: Scott Bradshaw
CC: Josh Bryson, Loren Burmeister
DATE: April 5, 2019
RE: Snow Melt Driven Flow Increase Definition

Introduction

The 2006 BPSOU Record of Decision (ROD) defined wet weather flow conditions as flow greater than 50 cubic feet per second (cfs) at monitoring station SS-07 in Silver Bow Creek or greater than 35 cfs at station SS-04 in Blacktail Creek. Subsequent monitoring has illustrated times when these specified wet weather flow conditions occur in the absence of precipitation within BPSOU and at adjacent monitoring stations (local precipitation). At times, wet weather flow conditions have been correlated to snow melt run-off events and/or precipitation events upstream in the BTC drainage. The condition of observed wet weather flow in absence of local precipitation demonstrated the need to differentiate between high flow conditions caused by snow melt run-off versus those caused by local precipitation events. Both wet weather and snow melt run-off events are highly variable, but unlike wet weather events, snow melt events are dependent on available snowpack and prolonged temperatures above 32° F.

This technical memorandum summarizes Atlantic Richfield's (ARs) review of flow response at Blacktail Creek station SS-04 (USGS station 12323240) to snow melt run-off. Station SS-04 was used because the data set (through October 2017) has been approved by the United States Geological Service (USGS) and station SS-04 captures flow increase due to snow melt events upstream of BPSOU. The purpose of this analysis is to numerically quantify the percent flow increase at SS-04 over a defined time period in response to a snow melt event.

Although snow melt run-off can occur any time of year, this discussion focuses on snow melt run-off between November and April. From late-April through June, precipitation is frequent; thus, stream flow increases can be associated with wet weather, snow melt, or a combination of both. Generally, upland snowpack diminishes by late June and upland accumulation does not begin until November. Snow melt run-off events between July and October are associated with precipitation events (snowfall) and subsequent run-off.

Snow Melt Driven Flow Increase Definition

The definition of a snow melt driven flow increase, for the purposes of this technical memorandum evaluation, is runoff caused by melting snow, either within BPSOU or in the upgradient Blacktail

Creek (BTC) watershed, in response to prolonged temperatures above freezing, and in the absence of local precipitation. The remainder of this technical memorandum provides numeric quantification of a snow melt driven run-off event as a mean percent flow increase above diurnal flow over a specified time period.

This snow melt driven run-off analysis utilized streamflow, daily maximum temperatures, and daily precipitation data from January 1, 2008 through December 31, 2018. Data sources included 15-minute flow values from USGS station 12323240 (SS-04); daily precipitation records from National Weather Service station KBTM (Bert Mooney Airport - BMMA); and daily minimum and maximum temperature data from BMMA. Since BMMA data is presented as daily values, data from two Atlantic Richfield weather stations were also consulted (BSB Shop and CB-1). Both Atlantic Richfield stations provide hourly, or more frequent, data from mid-April 2010 through the present. The Atlantic Richfield records were consulted when it was necessary to determine the hour in which local precipitation occurred. Snowpack data from the United States Department of Agriculture Natural Resources and Conservation Service Basin Creek (station 315) Snow Telemetry (SNOTEL) site was also consulted.

Methodology for Determining Snow Melt Driven Flow Increases

Table 1 presents data for several snow melt driven flow increases between 2008 and 2018. These events were the result of snow melt within Butte, or snow melt in upland areas within the BTC drainage. All of the snow melt driven flow increases occurred between late January and mid-April of the analysis time period. Snow accumulations prior to December of each year were minimal, and precipitation later than mid-April was so frequent that increases in stream flow could not be attributed to snow melt alone. The Table 1 snow melt driven flow increases were found by reviewing SS-04 hydrographs along with BMMA temperature and precipitation data. Criteria used to define snow melt driven flow increases were flow increases above median winter diurnal variation, temperature greater than 32° F on the day of and the day prior to the flow increase, no precipitation on the day of the flow increase, and < 0.05 inches of precipitation on the day prior to the flow increase. The data set was limited to November through April of each year. Snowpack data for the Basin Creek SNOTEL site was also consulted; however, the SNOTEL data showed upland snowpack does not begin diminishing until mid-to-late April, and often May.

Table [SEQ Table * ARABIC] – 2008-2018 Snow Melt Driven Run-off Event Summary

Date	High Temp Previous 3-day Mean (°F)	High Temp Previous Day (°F)	High Temp on Snowmelt Date (°F)	Temp Change from Previous Day (°F)	Temp Change from Previous 3-day Mean (°F)	% 1-day temp increase (°F)	% 3-day temp increase (°F)	Beginning Flow Time	Beginning Flow (cfs)	Peak Flow Time	Peak Flow (cfs)	Time from beginning to peak flow (hours)	% Flow Increase Beginning to Peak	Median Winter Diurnal Variation ¹ (%)	Increase above Median Winter Diurnal Variation (%)	Comment
03/09/08	39	39	44	5	5	13%	13%	14:00	8.7	17:45	14	3.75	61%	6.6%	54%	
03/11/08	44	50	48	-2	4	-4%	8%	12:45	9.5	18:00	25	5.25	163%	6.6%	157%	
04/13/08	48	57	68	11	20	19%	43%	2:15	15	23:45	19	21.5	27%	6.6%	20%	Flow began to increase slowly on 4/13/08 and peaked on 4/15/08.
04/14/08	57	68	70	2	13	3%	22%	0:00	19	23:45	27	23.75	42%	6.6%	36%	
04/15/08	65	70	39	-31	-26	-44%	-40%	0:00	28	17:15	46	17.25	64%	6.6%	58%	
04/21/10	68	70	70	0	2	0%	3%	5:15	29	16:00	39	10.75	34%	6.6%	28%	
02/15/11	34	32	31	-1	-3	-3%	-8%	13:00	15	16:45	33	3.75	120%	6.6%	113%	
04/01/11	59	65	46	-19	-13	-29%	-22%	11:00	35	23:30	51	12.3	46%	6.6%	39%	
03/04/12	33	43	51	8	18	19%	53%	14:45	15	17:30	21	2.75	40%	6.6%	33%	
03/21/12	34	39	47	8	13	21%	38%	12:00	20	17:00	51	5	155%	6.6%	148%	
03/22/12	39	47	60	13	21	28%	54%	3/22/12 14:30	29	3/23/12 0:15	43	9.75	48%	6.6%	42%	
03/13/13	45	48	56	8	11	17%	25%	15:00	11	19:00	20	4	82%	6.6%	75%	
03/09/14	44	47	49	2	5	4%	11%	14:15	13	19:15	44	5	238%	6.6%	232%	
04/07/14	46	47	56	9	10	19%	21%	4/7/14 17:45	20	4/8/15 0:15	39	6.5	95%	6.6%	88%	
04/08/14	49	56	64	8	15	14%	30%	12:45	22	23:15	53	10.5	141%	6.6%	134%	
01/25/15	40	45	54	9	14	20%	36%	13:15	11.4	17:00	24	3.75	111%	6.6%	105%	
02/06/15	43	51	55	4	12	8%	29%	13:30	12.9	23:00	44	9.5	238%	6.6%	231%	
02/16/16	43	44	45	1	2	2%	5%	12:15	12	16:00	21	3.75	74%	6.6%	68%	
03/05/16	49	52	57	5	8	10%	16%	12:15	13.8	19:00	19	6.75	35%	6.6%	28%	
03/14/17	51	57	60	3	9	5%	18%	10:30	28.5	22:45	73	12.25	157%	6.6%	151%	
03/22/18	42	45	47	2	5	4%	12%	12:30	15.2	20:45	57	8.25	274%	6.6%	267%	Precipitation on 3/22/18 but not until 21:00.
Max	68	70	70	13	21	28%	54%		35		73	23.75	274%		267%	
Min	33	32	31	-31	-26	-44%	-40%		8.7		14	2.75	27%		20%	
Mean	46	51	53	2	7	6%	18%		18		36	8.86	107%		100%	
Median	44	48	54	4	9	8%	18%		15		39	6.75	82%		75%	
1st Quartile	40	45	47	1	4	2%	8%		13		21	4	46%		39%	
3rd Quartile	49	57	60	8	13	19%	30%		22		46	10.75	155%		148%	

¹The overall median winter diurnal variation considered November, December, January, February, March, and April data for 1/1/08 through 12/31/18. Criteria were temperature <33°F on day being assessed and previous day, and precipitation of 0.00 inches on day being assessed and < 0.05 inches of precipitation on previous day.

Diurnal Stream Flow Variation

The below section provides a brief description of the method employed to determine the diurnal flow used in evaluating the flow increase associated with a snow melt run-off event. A more detailed description is provided in the attached calculation brief (Calc_Brief_DiurnalVariation).

Daily flow variation, in cubic feet per second (cfs), was determined for every day which had flow data available. This was a multi-step process which required converting 15-minute flow data into daily mean flows, calculating the maximum variation within a 24-hour period, and comparing the daily variation to the daily mean flow to find a percent diurnal variation. [REF _Ref3360136 \h] describes the calculation.

Equation [SEQ Equation * ARABIC] – Diurnal Variation = Max Daily Flow – Min Daily Flow

Percent daily diurnal variation was determined as the two-day rolling average variation divided by the two-day mean flow. The calculation is provided in [REF _Ref3360214 \h].

Equation [SEQ Equation * ARABIC] – Percent Daily Diurnal Variation = (2-day Rolling Average Diurnal Variation)/(2-day Rolling Average Mean Flow)

From the two-day rolling average diurnal variation, mean percent diurnal variations were determined for snowmelt periods. The goal was to determine streamflow fluctuations (diurnal variation) which occur in the absence of run-off events; thus, the data set was filtered to provide a winter time diurnal variation. Filter variables were month (November through April), precipitation, and maximum temperature. The data set was assessed day by day. The precipitation filter excluded days with greater than 0.00 inches of precipitation and previous days (1 day previous) in which greater than 0.04 inches of precipitation was recorded at BMMA. (example, Feb 2 precip = 0, Feb 1 precip < 0.05). The temperature filter excluded days with maximum temperatures greater than 32° Fahrenheit (°F), and days in which the previous day temperature was greater than 32° Fahrenheit (° F) (Feb 2 max temp <33, Feb 1 max temp < 33). Although snowmelt does not necessarily occur at 33° F, data is not available to determine a temperature that causes snow melt; thus, a limit of 32° F was chosen since that is the freezing point.

This method was applied to the winter and early spring months (November through April) to calculate an overall average winter percent diurnal variation. Determining the diurnal variation to be applied using only the winter months is based on the logic that only stream flow variations which occur in the absence of any run-off should be removed from snow melt run-off hydrographs. Although, frequent precipitation may occur in March and April, and temperatures reach well above freezing, the precipitation and temperature filters removed data points associated with precipitation and warm temperatures. Throughout May and June, precipitation is typically frequent; thus, those months were removed although snowpack remains in the upper Blacktail Creek drainage. In the majority of years, no snowpack is available from July through October; thus, those months were

excluded in determining snow melt related diurnal variation¹. The mean 2008-2018 diurnal variation determined by the above method was 8.2% (the median diurnal variation was 6.6%). It should be noted that the data set was not normally distributed. The count for the data set was 252.

Snow Melt Driven Flow Increase Definition

Snow melt driven flow increases occur under highly variable conditions. Naturally, the rate and intensity of a snow melt flow increase is a function of snowpack and exposure to ambient temperature in excess of 32° F. Seldom do stream flows increase significantly in response to single day elevated temperatures, rather it is two to three days of sustained temperatures in excess of 32° F that cause significant flow increases at SS-04. [REF _Ref3296942 \h] shows that the percent flow increase at SS-04 over a constant diurnal variation does not correlate well with same day temperature increase nor does ambient temperature on the day(s) of or day prior to a snow melt event correlate with percent flow increase at SS-04 for a given event, as [REF _Ref3296978 \h * MERGEFORMAT] shows. Counterintuitively, it was generally observed that increased flow conditions at SS-04 occurred on days that maximum temperatures decreased from previous days. The above factors suggest that snow melt event impact, measured as increased flow at SS-04, is delayed due to the travel time needed to reach the Butte area from the location of the snow melt event.

The median temperature on the day of flow increases caused by snow melt was 54° F, and the 3rd quartile temperature was 60° F. Maximum temperature on the day of snow melt flow increases was compared to (a): maximum temperature on the day preceding the flow and (b): the mean of the maximum temperatures for the three days preceding the flow. The median and 3rd quartile values for the preceding day were 48° F and 57° F. The median and 3rd quartile values for the preceding three-day mean were 44° F and 49° F, respectively. The data demonstrate that it is difficult to establish temperature, or temperature increase, criteria that defines a snow melt driven flow increase.

The percent flow increase was determined as the percent difference between the peak flow value at SS-04 resulting from a snow melt event and the stable flow value at SS-04 just prior to persistent flow increases. The average percent diurnal variation was then subtracted from the percent flow increase, to give a percent increase attributed to snow melt run-off only. For 2008 to 2018 data, the SS-04 median percent flow increase associated with snow melt run-off was 82%, and the first quartile percent increase was 46%. Subtracting the median winter diurnal variation of 6.6% from

¹ Stream flow diurnal variation is muted with the precipitation or snowmelt during spring months, and larger diurnal fluctuations are observed in mid-to-late summer months due to higher temperatures which allow in-stream vegetation growth, which may affect the flow regime. It is also possible that upstream discharges (irrigation) affect SS-04 flows in summer months. [REF _Ref3296036 \h * MERGEFORMAT] displays the SS-04 2014 hydrograph and [REF _Ref3296061 \h * MERGEFORMAT] displays flow variation seen in winter months and that seen in summer months. As [REF _Ref3296061 \h * MERGEFORMAT] shows, summer diurnal variation is nearly as great as the variation caused by winter month run-off events. [REF _Ref3296061 \h * MERGEFORMAT] demonstrates the appropriateness of using a winter month diurnal variation value in defining snow melt events.

these values results in a SS-04 median flow increase due to snowmelt of 75% and a 1st quartile flow increase of 39%. Subtracting the diurnal variation from the observed increase provisions an exclusion of false-positive indications of snow melt.

Time to reach peak flow at SS-04 as a result of a snow melt event was assessed by calculating the time between stable flow just prior to persistent flow increases and peak flow for the snow melt driven event. [REF _Ref3297093 \h] demonstrates the method for a single event, and Table 1 presents the data for all events used in the assessment. As Table 1 shows, the times between stable flow and peak flow were highly variable, with a range of 2.75 hours to 23.75 hours. The mean time to reach peak flow was 8.9 hours, the median time to reach peak flow was 6.75 hours, and the third quartile time to reach peak flow was 10.75 hours. These lengthy times are indicative of consistent, steady run-off over prolonged periods.

Conclusion

While many variables affect snow melt run-off volumes, the two variables which should be considered in this application include percent flow increase over diurnal average and time to reach peak flow. Twenty-one snow melt driven flow increases between 2008 and 2018 were assessed, and the median increase over the average winter diurnal flow variation was 75% and the 1st quartile increase was 39%. The median time to reach peak flow was 6.75 hours, and the third quartile time to reach peak flow was 10.75 hours. A conservative approach is to consider the data set 1st quartile flow increase over the median winter diurnal variation and the 3rd quartile time to reach peak flow. The 1st quartile increase captures flow increases at times that streamflow has been previously elevated and additional snow melt occurs, and it captures situations when snowpack is minimal. Use of the rounded third quartile time allows ample time for streamflow to respond to upland snow melt. Thus, a snow melt driven flow increase can be numerically quantified at SS-04 as a flow increase of at least 40% (rounded from 39%) within a twelve hour period or less.

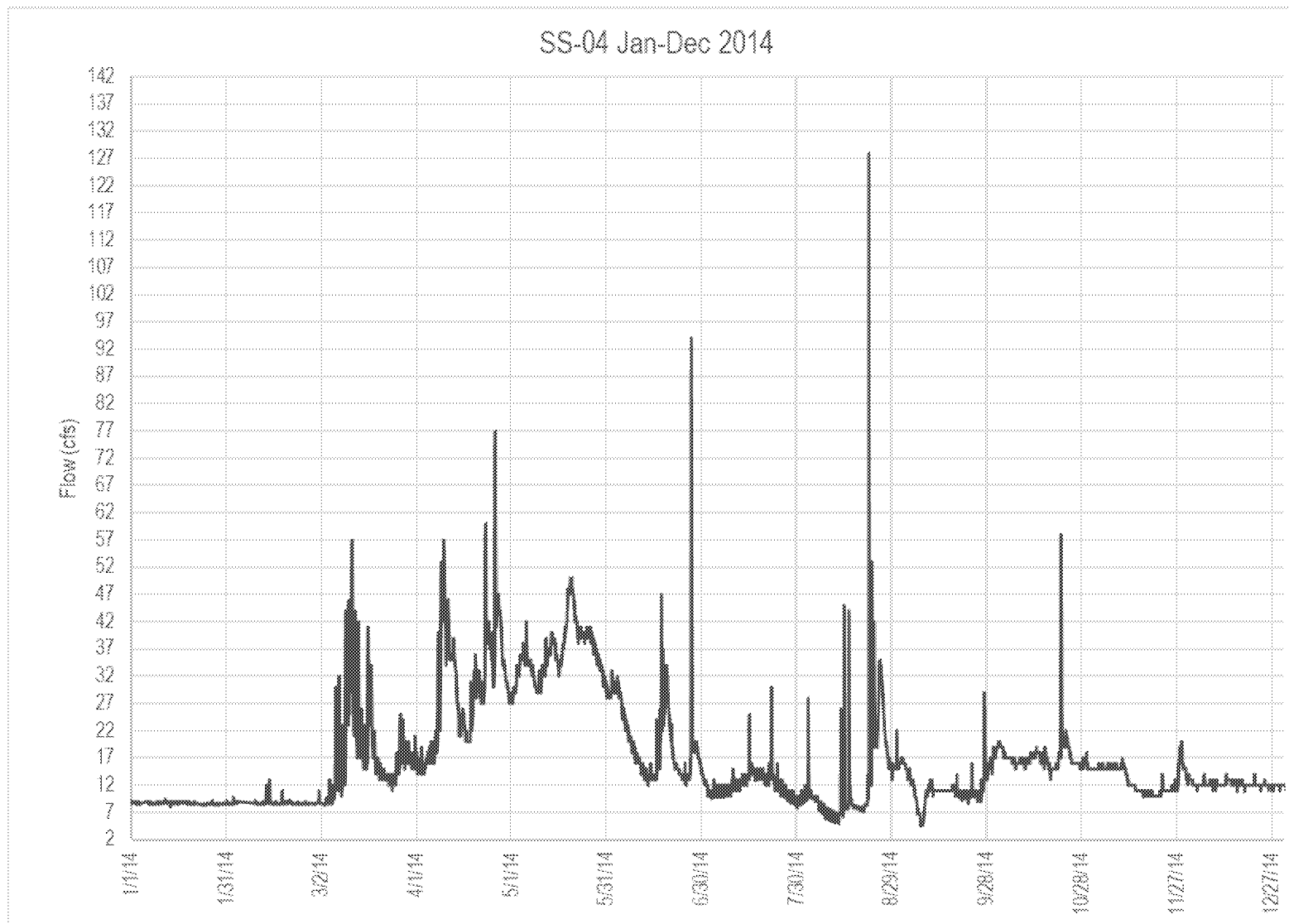


Figure [SEQ Figure * ARABIC] – January – December 2014 SS-04 Hydrograph Demonstrating Seasonal Diurnal Variation

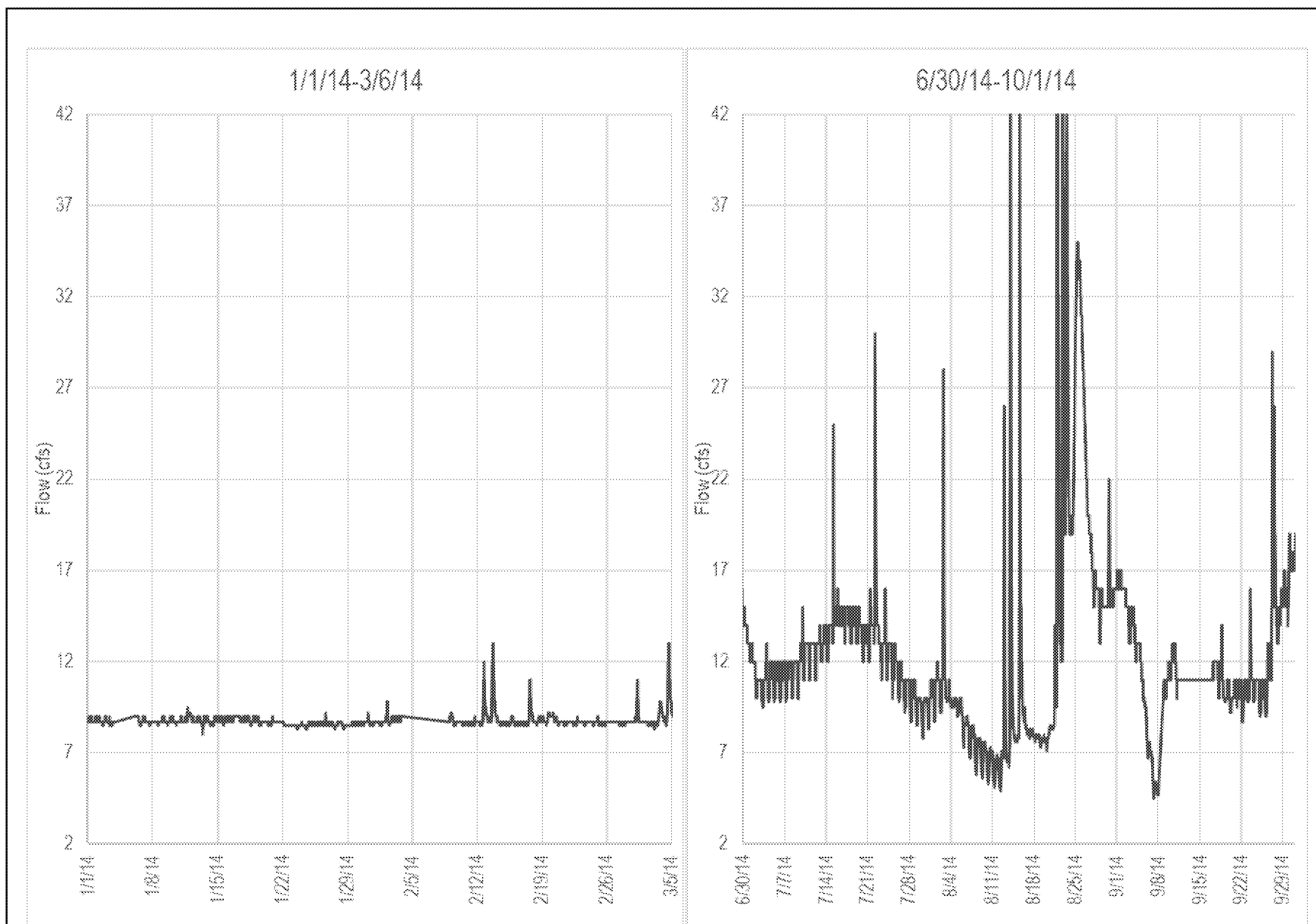


Figure [SEQ Figure * ARABIC] – Comparison of Winter and Summer Diurnal Variation at SS-04

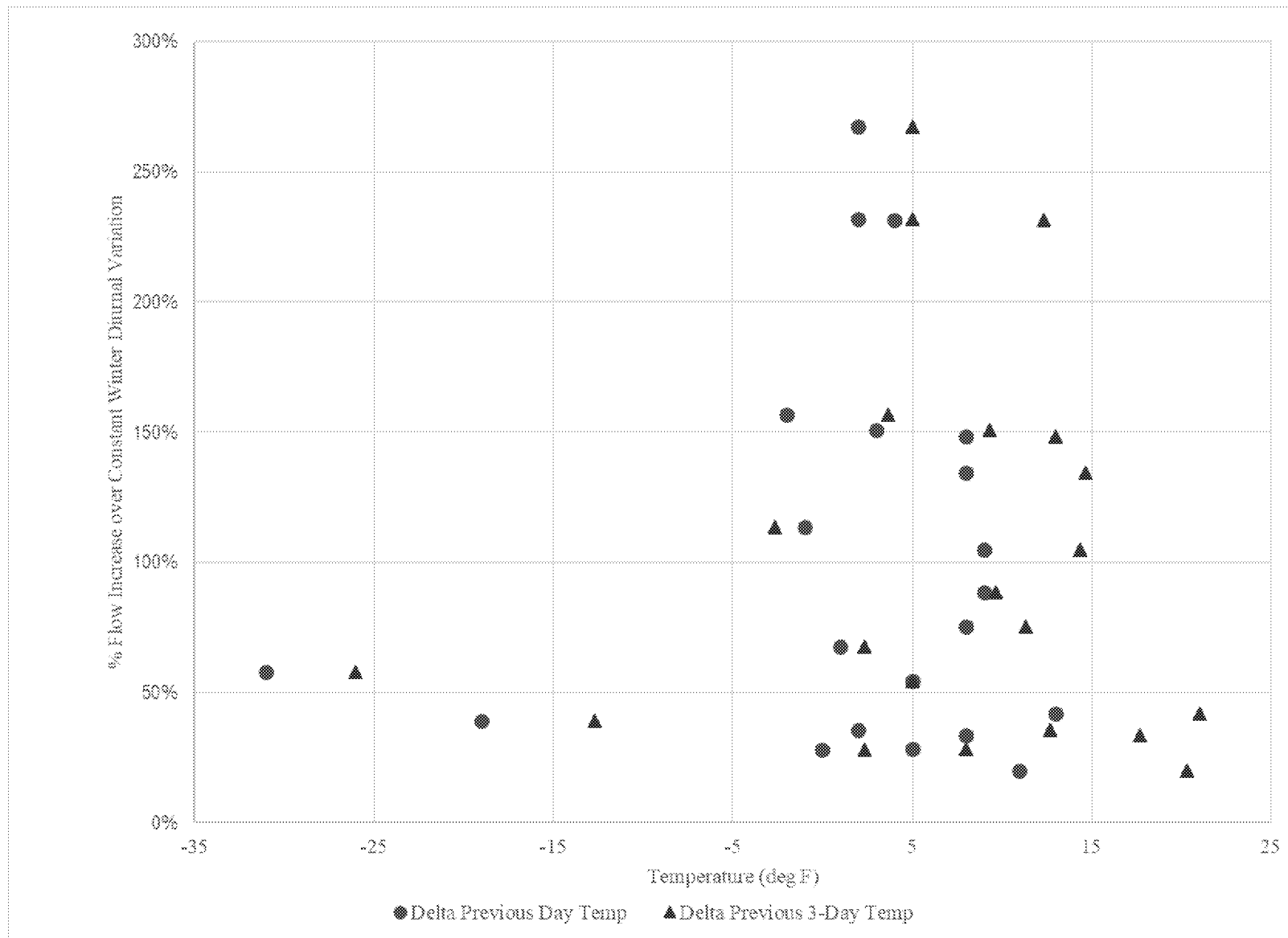


Figure [SEQ Figure * ARABIC] – Temperature Change (°F) versus Percent Flow Increase Over Median Winter Diurnal Variation

[PAGE * MERGEFORMAT]

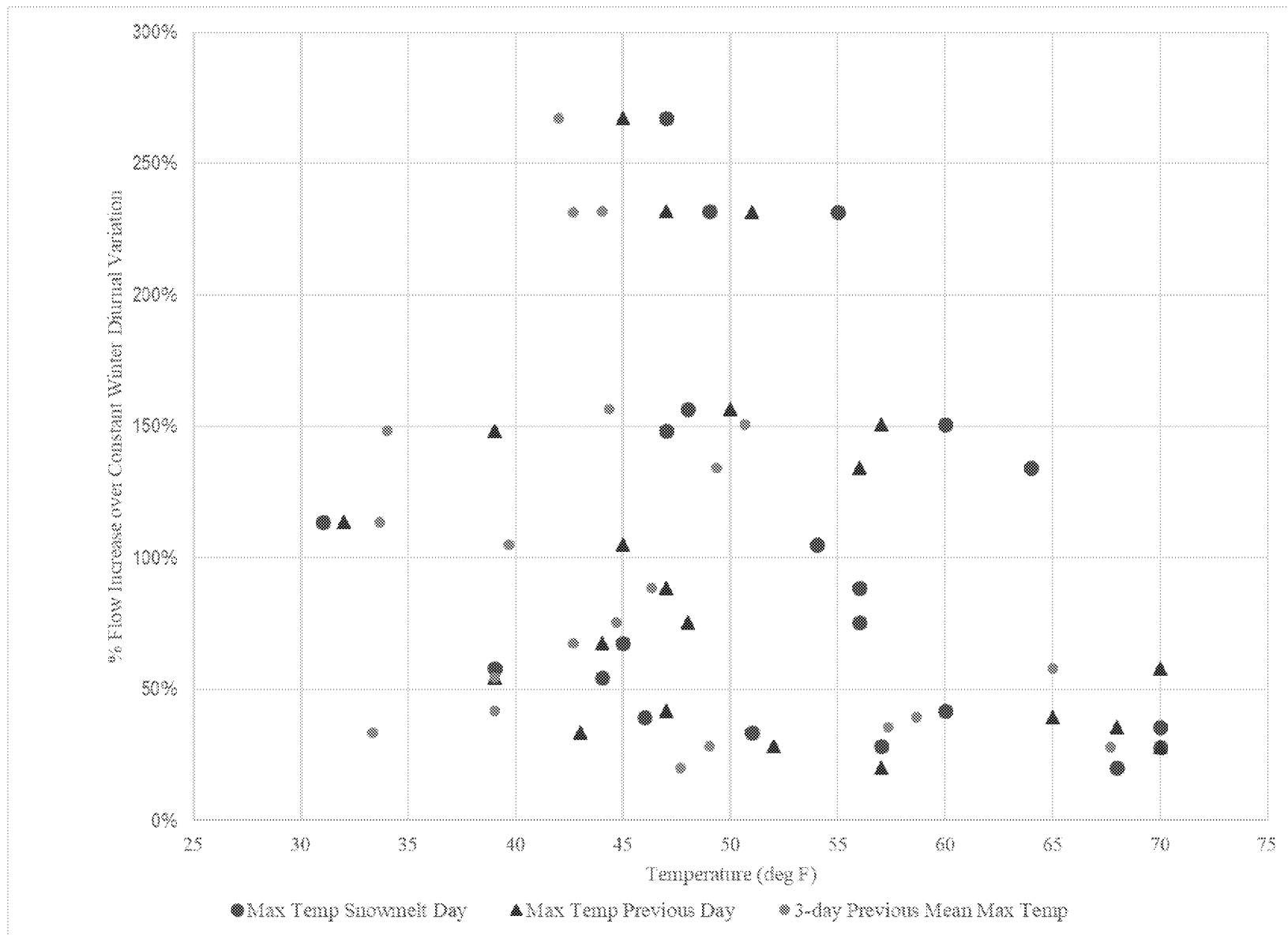


Figure [SEQ Figure * ARABIC] - Temperature (°F) versus Percent Flow Increase Over Median Winter Diurnal Variation

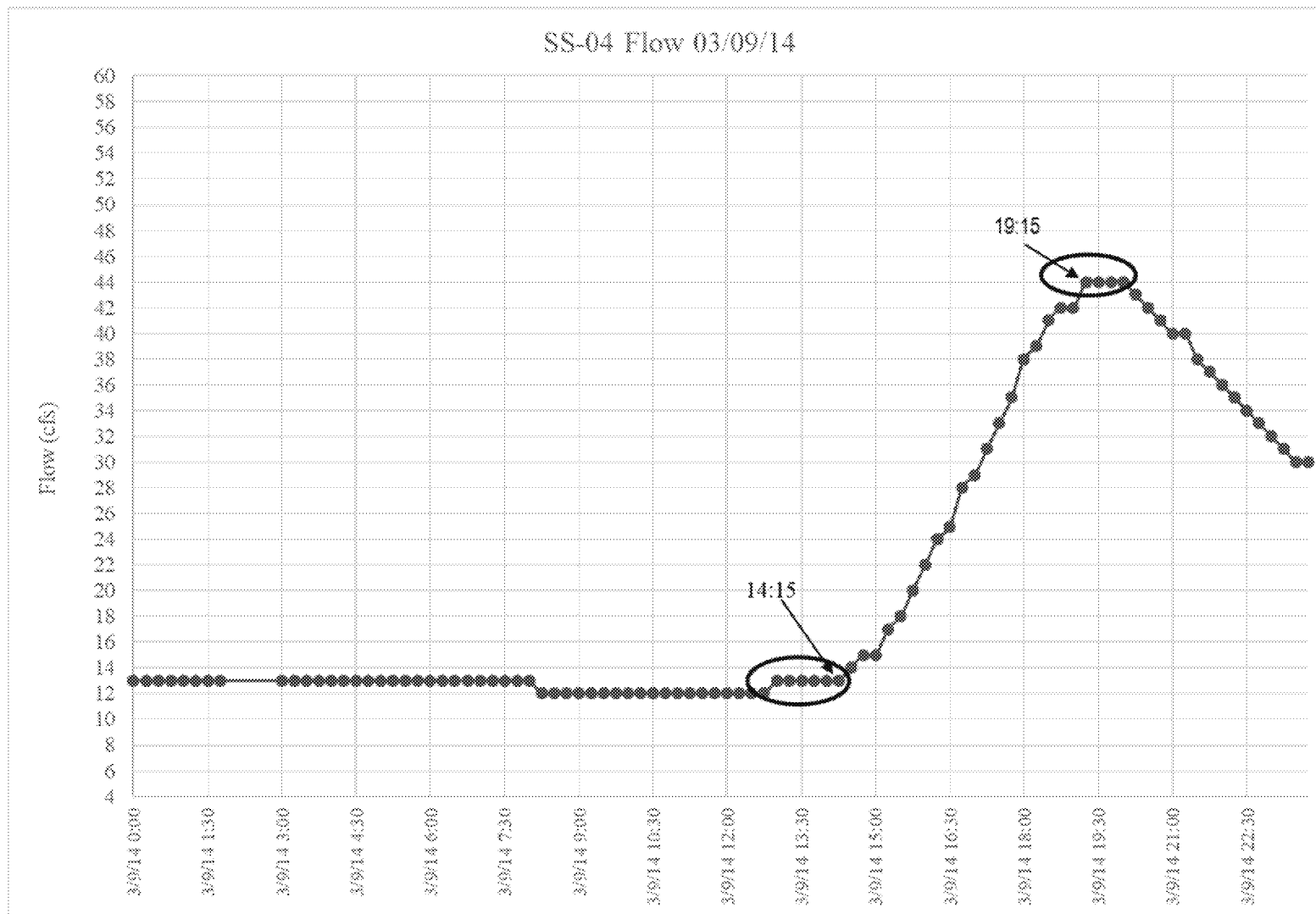


Figure [SEQ Figure * ARABIC] – Illustration of Method used to Determine Time Difference between Stable Flow and Peak Snowmelt Run-off Flow

Created/Reviewed		Date	Description	Project
Originator	TMD	4/2/19	Wintertime diurnal variation at SS-04	9208 – 2009 BPSOU
Checked	EKS	4/2/19		File Name:
Approved				Calc_Brief_DiurnalVariation.docx
Level 1:			Level 2:	Level 3:

PURPOSE:

The purpose of this calculation brief is to determine diurnal flow variation in winter months at USGS surface water station 12323240. USGS 15-minute flow data from January 1, 2008 through December 31, 2018, National Weather Service station KBTM at Bert Mooney Airport (BMMA) daily precipitation, and BMMA daily maximum temperature data were used. These calculations aid in determining the percent flow increase due to snow melt that defines a snow melt driven flow increase at SS-04. Once winter diurnal variation was determined, it was subtracted from the snow melt driven flow increase to define a flow increase that could be attributed to snow melt alone.

METHODS:

January 1, 2008 through December 31, 2018 15-minute flow data for USGS station 12323240 (SS-04) were retrieved from the USGS real time streamflow website and tabulated. The USGS data are approved and official through November 2, 2017. January 1, 2008 through December 31, 2018 daily precipitation and maximum temperature data for National Weather Service station KBTM (Bert Mooney Airport - BMMA) data were also tabulated.

SS-04 15-minute flow data were averaged (from 00:00 to 23:45) to calculate daily average flow values. Maximum daily flow variation was then determined by calculating the difference between the maximum 15-minute flow value and the minimum 15-minute flow value (00:00 to 23:45). This difference was the diurnal variation. A two-day rolling average diurnal variation was calculated for each day in the data set by averaging (Day2Variation and Day1Variation), (Day3Variation and Day2Variation), (Day4Variation and Day3Variation), and so on. A percent diurnal variation was calculated as (2-day Rolling Average Diurnal Variation)/(2-day Average Flow). This provided diurnal variation for the entire data set.

Year-round diurnal variation was not of interest. The end objective was to assess flow increases that are caused by local and upland snowmelt, in the absence of local (Butte area) precipitation. These conditions typically occur in winter months. Therefore, the diurnal variation calculations were filtered to meet the criteria below.

ASSUMPTIONS

- Winter month diurnal variation is minimal compared to spring/summer diurnal variation.
- Snowmelt does not occur in the absence of precipitation between July and October of each year.
- Precipitation is so frequent between May and July 1, that diurnal variation is precipitation driven.

Created/Reviewed		Date	Description	Project
Originator	TMD	4/2/19	Wintertime diurnal variation at SS-04	9208 – 2009 BPSOU
Checked	EKS	4/2/19		File Name:
Approved				Calc_Brief_DiurnalVariation.docx
Level 1:			Level 2:	Level 3:

CRITERIA:

- Only data from November through April of each year were considered based on the above assumptions.
- No precipitation was recorded at BMMA on the date being assessed.
- Less than 0.05 inches of precipitation was recorded on the day previous to the one being assessed.
- The maximum daily temperature recorded at BMMA on the date being assessed and the date previous to the one being assessed was less than 33° Fahrenheit.

CALCULATIONS:

Equation [SEQ Equation * ARABIC]: **Diurnal Variation (cfs) = Max Daily Flow (cfs) – Min Daily Flow (cfs)**

15-minute data was used for Equation 1. The minimum 15-minute flow value was subtracted from the maximum 15-minute flow value.

Equation [SEQ Equation * ARABIC]: **Percent Daily Diurnal Variation (%) = (2-day Rolling Average Diurnal Variation)/(2-day Rolling Average Mean Flow)*100**

Equation [SEQ Equation * ARABIC]: **Winter time Diurnal Variation = Diurnal Variation filtered for precipitation and temperature**

Limited to November through April data, precipitation on day being assessed = 0.00 inches, precipitation on previous day < 0.05 inches, temperature on day being assessed and previous day < 33° F.

RESULTS/CONCLUSIONS:

SS-04 Mean Year-round diurnal variation:	SS-04 Winter time diurnal variation count:
SS-04 Median Year-round diurnal variation:	23.3% of mean daily streamflow
SS-04 Mean Winter time diurnal variation:	14.5% of mean daily streamflow
SS-04 Median Winter time diurnal variation:	8.2% of mean daily streamflow
SS-04 Year-round diurnal variation count:	6.6% of mean daily streamflow



CALCULATION BRIEF

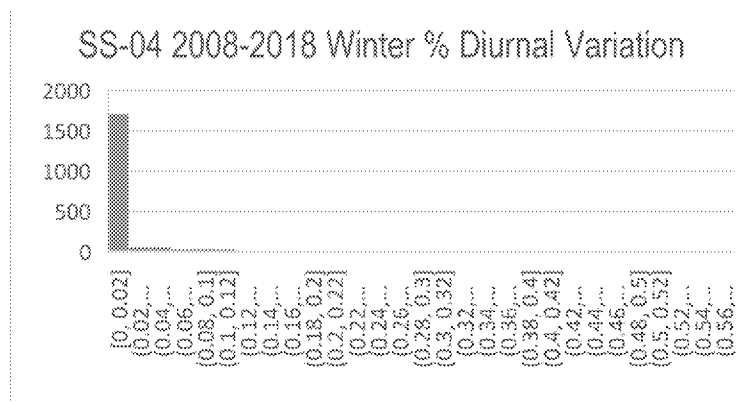
Created/Reviewed		Date	Description	Project
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Level 1:			Level 2:	Level 3:

3926 data points

267 data points

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Level 1:			Level 2:	Level 3:

Winter time diurnal variation is much less than year-round diurnal variation. The winter month diurnal variation data is skewed to the right; thus, the median is the appropriate average value to use.



REFERENCES:

USGS Continual Flow Data: [[HYPERLINK](#)

"https://waterdata.usgs.gov/mt/nwis/uv/?site_no=12323240&PARAMeter_cd=00060,00065,00010"]

NWS station KBTM (Bert Mooney Airport): [[HYPERLINK](#) "<https://www.ncdc.noaa.gov/cdo-web/search>"]

USDS NRCS SNOTEL DATA: [[HYPERLINK](#)

"https://wcc.sc.egov.usda.gov/reportGenerator/view_csv/customGroupByMonthReport/daily/315:MT:SNTL%7Cid=%22%22%7Cname/POR_BEGIN,POR_END/WTEQ::value"]